World Meteorological Organization

Working together in weather, climate and water

Outcomes from the Coupled Chemistry Meteorology/Climate Modelling Symposium (WMO, 2015) and EuMetChem COST Action

Alexander Baklanov

& EuMetChem, MEGAPOLI, GURME, WGNE & CCMM teams

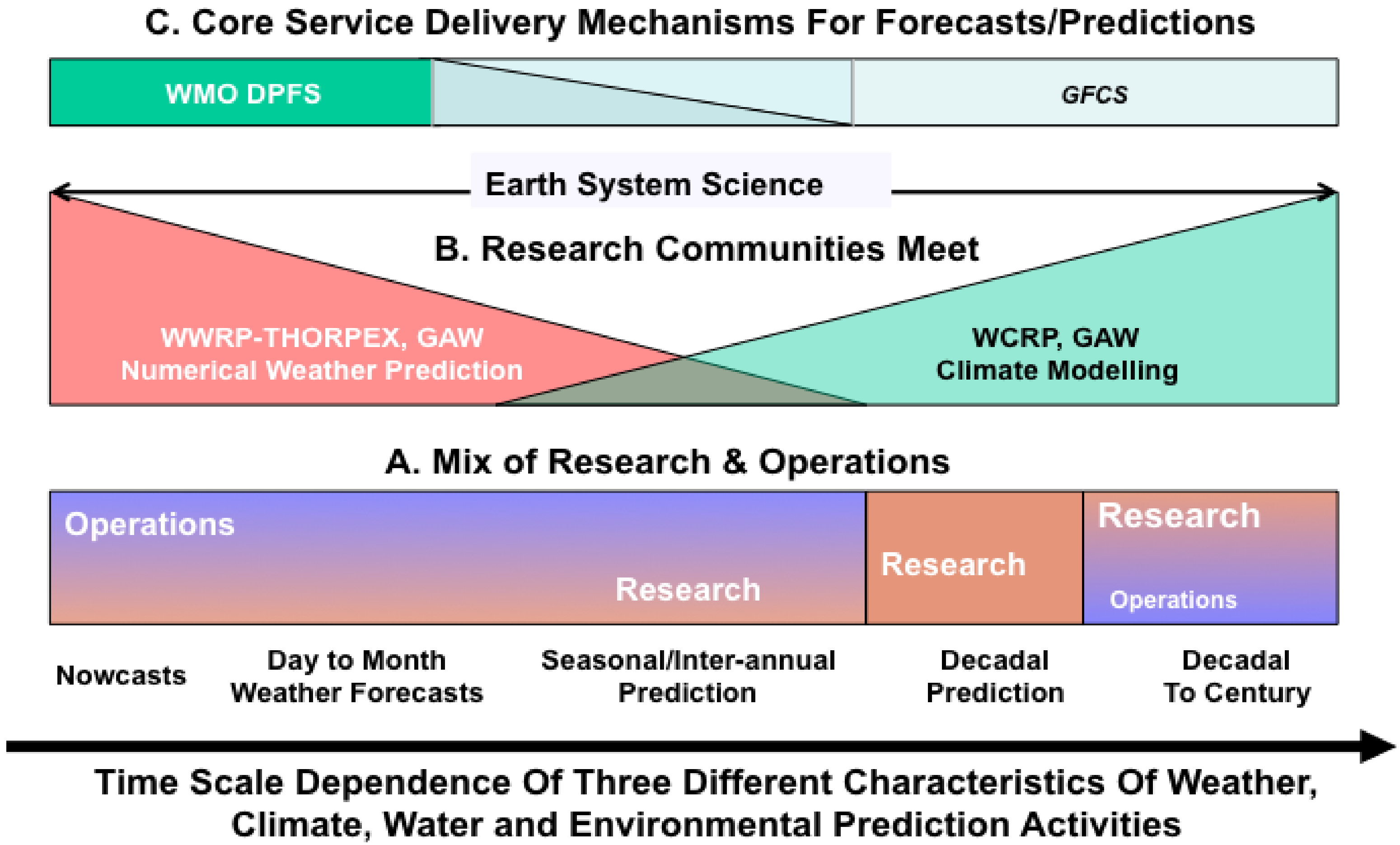
WMO GAW and WWRP, Geneva

7th International Workshop on Air Quality Forecasting Research

NOAA Center for Weather and Climate Prediction

College Park, Maryland, September 1—3, 2015

Seamless prediction



WMO WWOSC 'Seamless Earth System Modelling' Book:

http://library.wmo.int/pmb_ged/wmo_1156_en.pdf

European Cooperation in the field of Scientific and Technical Research

www.cost.esf.org

Action COST ES1004

European framework for online integrated air quality and meteorology modelling (EuMetChem)

ESSEM

www.eumetchem.info

COST countries: AT, BG, CH, DE, DK, EE, ES, FI, FR, GB, GR, HU, IL, IT, MT, NL, NO, PL, PT, RS, SE, SI, TR

Chair of the Action: Alexander Baklanov, DMI, Denmark, alb@dmi.dk

Co-Chairs: Sylvain Joffre, FMI, Finland; **Heinke Schluenzen**, Uni Hamburg, Germany

COST Science Officer: Deniz Karaca, Deniz.Karaca@cost.eu





The overall objective is to set up a multi-disciplinary forum for online integrated air quality/meteorology modelling and to elaborate an European strategy for an integrated ACT/NWP-CLIM modelling capability/framework.

Benefits for the Society

This European action (involving also key American experts) will enable the EU to develop world class capabilities in integrated ACT/NWP-RCM modelling systems, including research, education and forecasting. More than 40 teams from 19 European COST countries, as well as ECMWF, JRC, WMO, US EPA, NOAA, etc. are already involved in the Action. In detail the action will contribute to

•a better forecasting of severe weather events and their consequences (forest fires, dust storms, flooding, volcano eruption, etc.)

The Action aims towards a new generation of online integrated Atmospheric Chemical Transport (ACT) and Meteorology modelling systems (NWP and RCM) using two-way interactions between different atmospheric processes including chemistry, clouds, radiation, boundary layer, emissions, meteorology and climate (Fig. 1). The Action intends to consider at least two application areas of integrated modelling:

i.improved numerical weather prediction (NWP) and chemical weather forecasting (CWF) with short-term feedbacks of aerosols and chemistry on meteorological variables,

ii.two-way interactions between atmospheric pollutions / composition and climate variability / change.

The action covers four working groups:

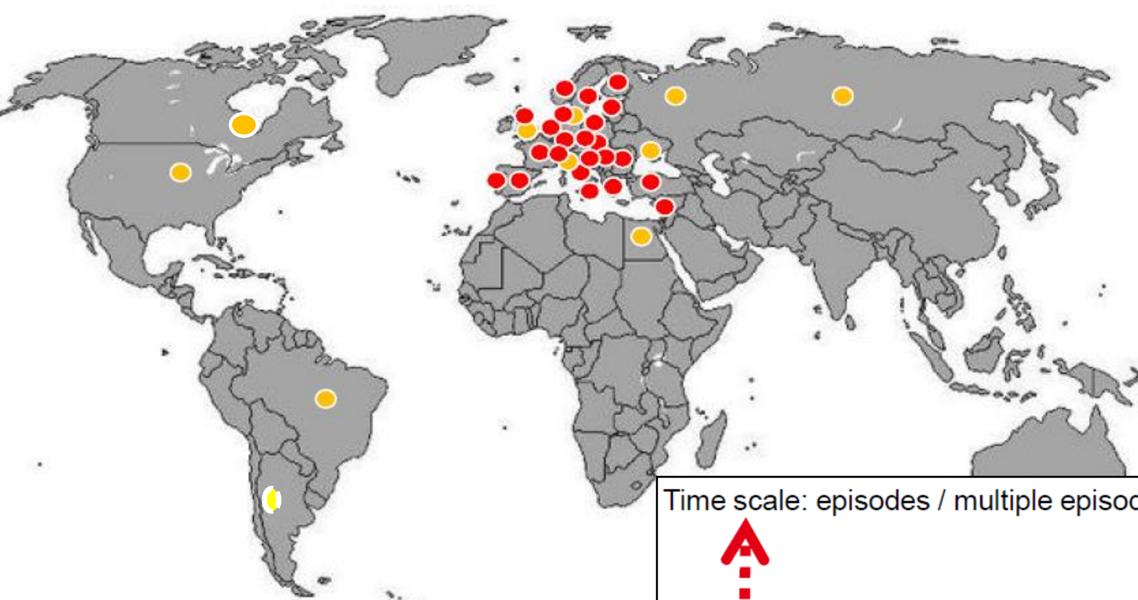
WG1 Strategy and framework for online integrated modelling (coordinated by Peter Suppan and Jose M. Baldasano),

WG2 Interactions, parameterisations and feedback mechanisms (coordinated by Michael Gauss and Alberto Maurizi),

WG3 Chemical data assimilation in integrated models (coordinated by Christian Seigneur and Hendrik Elbern),

WG4 Evaluation, validation, and applications (coordinated by Dominic Brunner and

Collaboration with COST Action ES1004 EuMetChem: European Framework for Online Integrated Air Quality and Meteorology Modelling



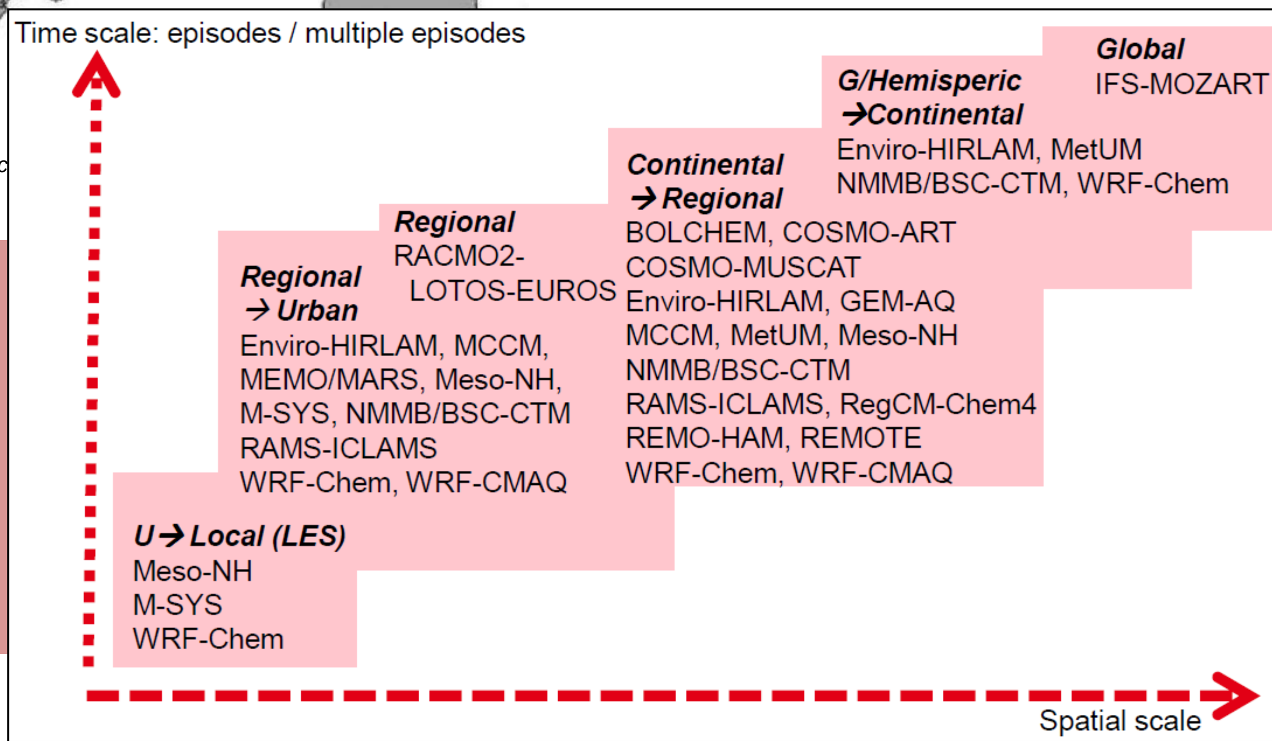
Base map: © 2004-2009 sc

- **Strategy and framework for online integrated modelling**
  - 17 experts (P. Suppan, J.M. Baltasano, G. Grell).
- **Interactions, parameterisations and feedback mechanisms**
  - 22 experts (M. Gauss, A. Maurizi, Y. Zhang).
- **Chemical data assimilation in integrated models**
  - 13 experts (Ch. Seigneur, H. Elbern, G. Carmichael).
- **Evaluation, validation, and applications**
  - 33 experts (D. Brunner, K.H. Schlünzen, S. Galmarini, S.T. Rao).

(Duration: 02.2011 … 02.2015)

Chair: A. Baklanov,
Co-chairs: S. Joffre, H. Schluenzen

23 COST countries
4 COST neighbour countries
3+2 COST partner countries
3 EU institutions
18 online models analysed =>



Overview of European progress in AQF and CCMM

Atmos. Chem. Phys., 12, 1–87, 2012
www.atmos-chem-phys.net/12/1/2012/
doi:10.5194/acp-12-1-2012

Atmospheric Chemistry and Physics

A review of operational, regional-scale, chemical weather forecasting models in Europe

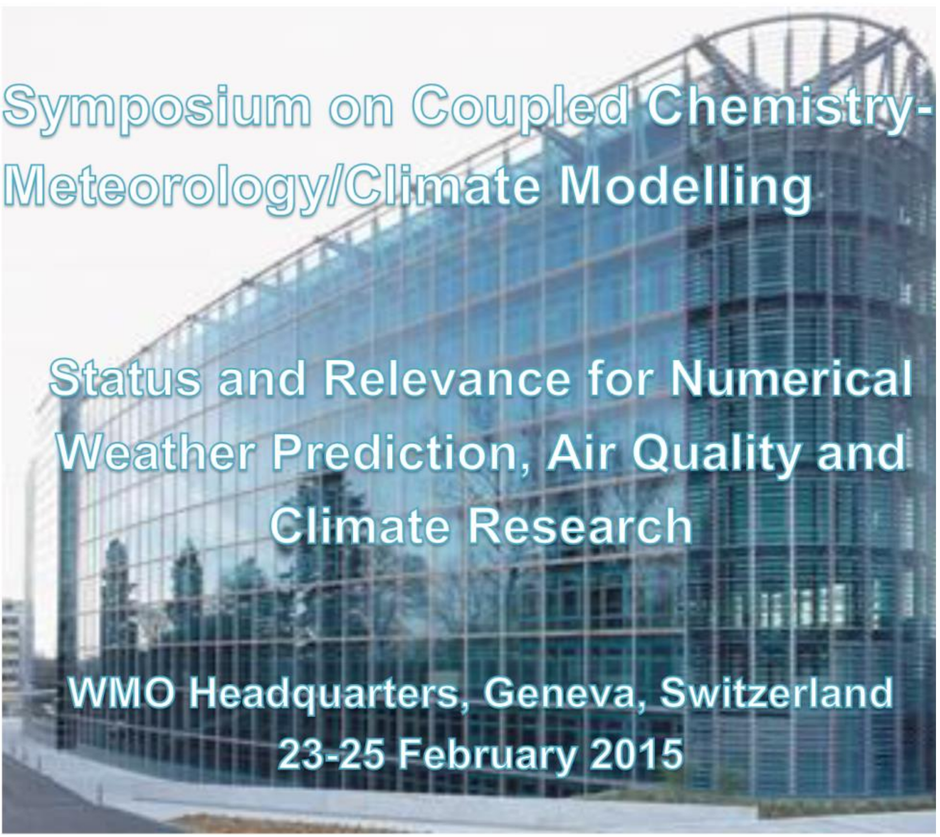
J. Kukkonen[1], T. Olsson[1,2], D. M. Schultz[1,2,3], A. Baklanov[4], T. Klein[5], A. I. Miranda[6], A. Monteiro[6], M. Hirtl[7], V. Tarvainen[1], M. Boy[2], V.-H. Peuch[8,9], A. Poupkou[10], I. Kioutsioukis[10], S. Finardi[11], M. Sofiev[1], R. Sokhi[12], K. E. J. Lehtinen[13,14], K. Karatzas[15], R. San José[16], M. Astitha[16], G. Kallos[18], M. Schaap[19], E. Reimer[20], H. Jakobs[21], and K. Eben[22]

Atmos. Chem. Phys., 14, 317–398, 2014
www.atmos-chem-phys.net/14/317/2014/
doi:10.5194/acp-14-317-2014

Atmospheric Chemistry and Physics
Open Access

Online coupled regional meteorology chemistry models in Europe: current status and prospects

A. Baklanov[1], K. .Schlünzen[2], P. Suppan[3], J. Baldasano[4], D. Brunner[5], S. Aksoyoglu[6], G. Carmichael[7], J. Douros[8], J. Flemming[9], R. Forkel[3], S. Galmarini[10], M. Gauss[11], G. Grell[12], M. Hirtl[13], S. Joffre[14], O. Jorba[4], E. Kaas[15], M. Kaasik[16], G. Kallos[17], X. Kong[18], U. Korsholm[1], A. Kurganskiy[19], J. Kushta[17], U. Lohmann[20], A. Mahura[1], A. Manders-Groot[21], A. Maurizi[22], N. Moussiopoulos[8], S. T. Rao[23], N. Savage[24], C. Seigneur[25], R. S. Sokhi[18], E. Solazzo[10], S. Solomos[17], B. Sørensen[15], G. Tsegas[8], E. Vignati[10], B. Vogel[26], and Y. Zhang[27]



100 participants from all continents
46 oral talks, 36 posters,
All presentations are available on:
http://eumetchem.info/
7 topics brain-storm teams to conclude
WMO Report to be published
ACP & GMD Journal CCMM Special Issue
Outcomes provided for 17th WMO Congress

Topics

- Coupled chemistry-meteorology (weather and climate) modelling (CCMM): approaches and requirements;
- Key processes of chemistry-meteorology interactions and their descriptions;
- Aerosol effects on meteorological processes and NWP;
- CCMM for air quality and atmospheric composition;
- CCMM for regional and global climate modelling;
- Model validation and evaluation;
- Data requirements, use of observations and data assimilation;
- Outlook and future challenges.

Organizing Committee and Programme Committee

Alexander Baklanov (WMO), Jose M Baldasano (ES), Veronique Bouchet (CN), Dominik Brunner (CH), Greg Carmichael (US), Renate Forkel (DE), Saulo Freitas (BR), Stefano Galmarini (JRC, EU), Michael Gauss (NO), Georg Grell (US), Christian Hogrefe (US), Øystein Hov (NO), Sylvain Joffre (FI), Rohit Mathur (US), Nicolas Moussiopoulos (GR), Vincent-Henri Peuch (ECMWF), S.T. Rao (US), Michel Rixen (WCRP), K. Heinke Schlünzen (DE), Christian Seigneur (FR), Peter Suppan (DE), Bernhard Vogel (DE)

Venue

The CCMM Symposium will take place at the WMO Headquarters in Geneva. The airport and main train are in easy reach by public transport and offer excellent traffic links to the whole world.

Initiated and supported by

European Cooperation in Science and Technology (COST) Action ES1004: http://www.eumetchem.info/, World Meteorological Organization (WMO) Commission for Atmospheric Sciences (CAS) and World Climate Research Programme (WCRP).

Key scientific questions:

- What are the advantages of integrating meteorological and chemical/aerosol processes in coupled models?
- How important are the two-way feedbacks and chains of feedbacks for meteorology, climate, and air quality simulations?
- What are the effects of climate/meteorology on the abundance and properties (chemical, microphysical, and radiative) of aerosols on urban/regional/global scales?
- What is our current understanding of cloud-aerosol interactions and how well are radiative feedbacks represented in NWP/climate models?
- What is the relative importance of the direct and indirect aerosol effects as well as of gas-aerosol interactions for different applications (e.g., for NWP, air quality, climate)?
- What are the key uncertainties associated with model predictions of feedback effects?
- How to realize chemical data assimilation in integrated models for improving NWP and air quality simulations?
- How the simulated feedbacks can be verified with available observations/datasets? What are the requirements for observations from the three modelling communities?

Importance and Representation of Aerosol-chemistry-meteorology interactions for NWP, CWF and Climate models

Table 1 List of meteorology-chemistry interactions

1	Temperature → reaction rates
2	Radiation → reaction rates
3	Temperature → biogenic emissions
4	Radiation → photosynthesis → biogenic emissior
5	Temperature → volatility of species
6	Temperature → aerosol dynamics
7	Liquid water → wet scavenging, concentrations
8	Temperature & humidity → gas/particle partition
9	Precipitation (frequency/intensity) → concentrati
10	Soil moisture → dust emissions
11	Soil moisture → dry deposition (biosphere and sc
12	Wind speed → dust & sea salt emissions
13	Temperature vertical gradients → vertical diffusic
14	Lighting → NO_x emissions
15	Water vapour → OH radicals → ozone
16	Aerosols→SW scattering/absorption, LW absorpt
17	Radiatively active gases → radiation
18	Aerosol → haze
19	Soot deposition → ice albedo
20	Aerosol → cloud droplet/crystals → cloud O.D.
21	Aerosol → cloud morphology (e.g., reflectance)
22	Aerosol → precipitation (initiation, intensity)
23	Climate change → forest fire emissions
24	Changes in land surface → BVOC emissions

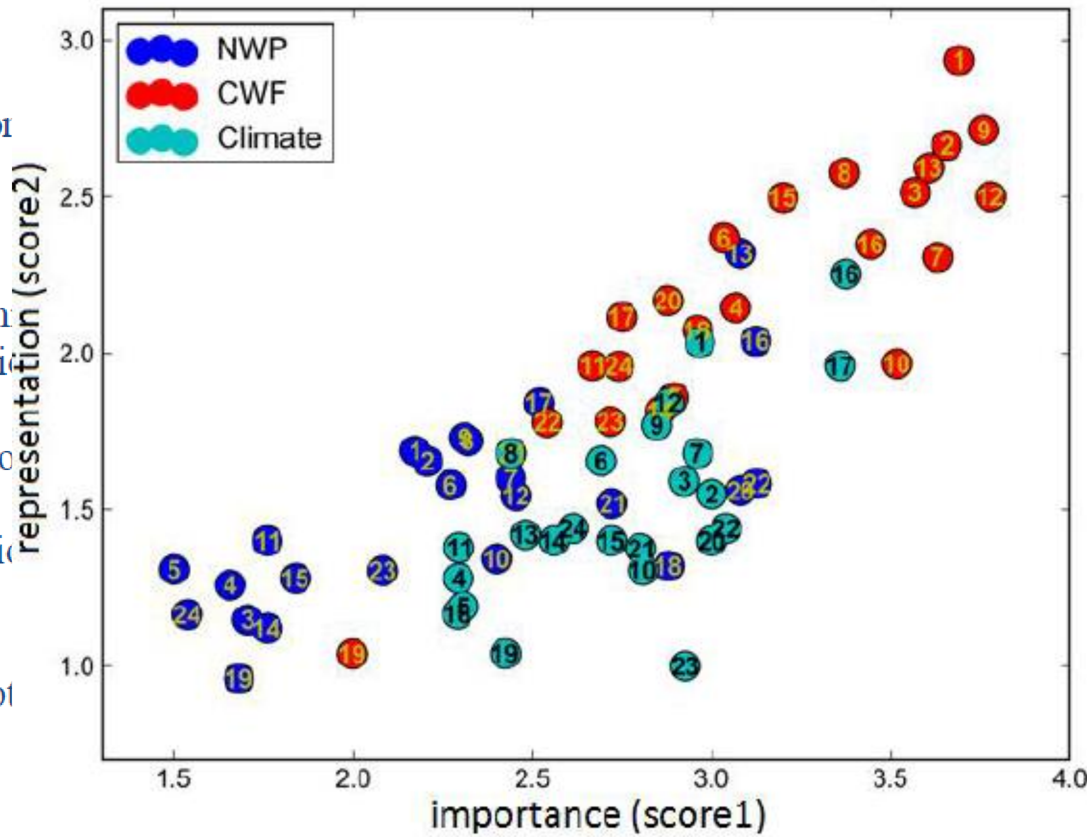
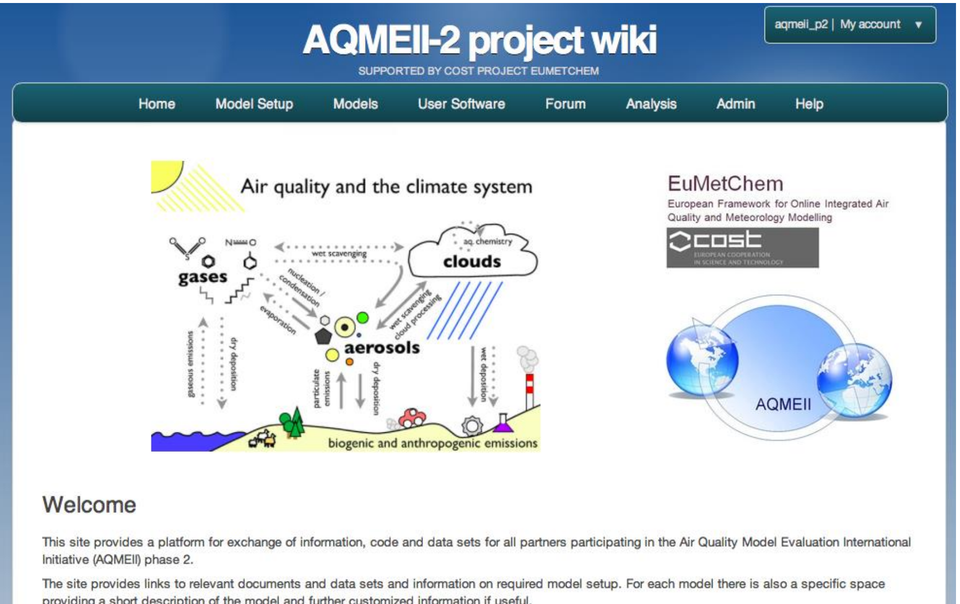
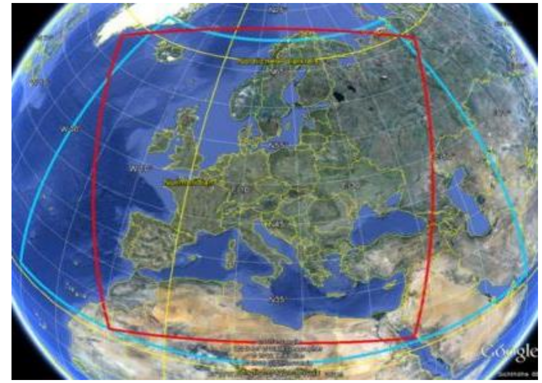


Figure 1 COST ES1004 expert survey results

Baklanov et al., ACP, 2014
Kong et al., AQC, 2014

EuMetChem in AQMEII online models evaluation exercise





European domain

Year 2010

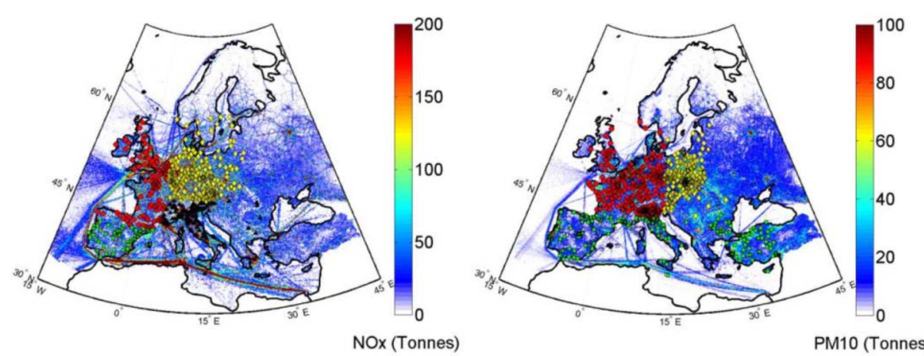
Selected case studies for aerosol feedbacks:

1. Russian forest fires, summer 2010
2. Sahara dust episode over Europe
3. MEGAPOLI Paris measurement campaign

	Groups	Domain	Met Model	CTM	Resolution	Biogenic Model	Gas Phase	Reference
M1	NL2	EU	RACMO	LOTOS-EUROS	0.5?×0.25?	Guenther et al., 1991	CB-IV	Segers A., 2013
M2	BG1	EU	WRF	CMAQ	25 km	BEIS	CB-IV	Byun and Schere, 2006
M3	SI1	EU	WRF	CHEM	23 km	MEGAN	RADM2	Grell et al., 2005
M4	IT2	EU	WRF	CHEM	23 km	MEGAN	RACM	Grell et al., 2005
M5	DE4	EU	WRF	CHEM	[illegible]	[illegible]	RADM2	Grell et al., 2005
M6	IT1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] et al., 2005
M7	CH1	EU	COSMO	COSMO-ART	0.22°		RADM2K	Vogel et al., 2009
M8	UK5	EU	[illegible]	CMAQ	[illegible]	[illegible]	[illegible]	[illegible], 2012
M9	UK4	EU	MetUM	UCKA RAQ	0.22 °		UCKA RAQ	[illegible], 2013
M10	ES1	EU	WRF	CHEM	23 km	MEGAN	RADM2	Grell et al., 2005
M11	ES2a	EU	NMM	BSC-CTM	0.20 °	MEGAN	CB-V	Jorba et al., 2012
M12	DE3	EU	COSMO	MUSCAT	0.25°	Gunther et al., 1993	RACM-MIM2	Renner and Wolke, 2010
M13	AT1	EU	WRF	CHEM	23 km	MEGAN	RADM2	Grell et al., 2005
M14	ES3	EU	WRF	CHEM	23 km	MEGAN	CBMZ	Grell et al., 2005
M15	ES1	NA	WRF	CHEM	36 km	MEGAN	RADM2	Grell et al., 2005
M16	US6	NA	WRF	CMAQ	12 km	BEIS3.14	CB-V-TU	Wong et al., 2012
M17	CA2	NA	GEM	MACH	15 km	BEIS	ADOM-II	???
M18	US7	NA	WRF	CHEM	36 km	MEGAN	MOZART	Grell et al., 2005
M19	US8	NA	WRF	CHEM	36 km	MEGAN	CB05	Grell et al., 2005
M20	ES3	NA	WRF	CHEM	36 km	MEGAN	CBMZ	Grell et al., 2005

14 models for EU domain (but only 7 individual models)

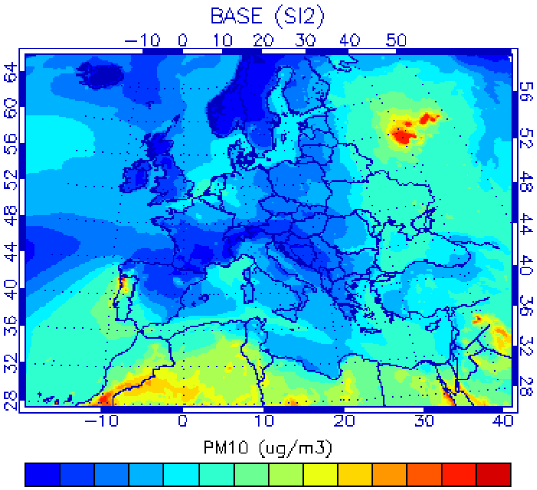
Collective analysis by JRC

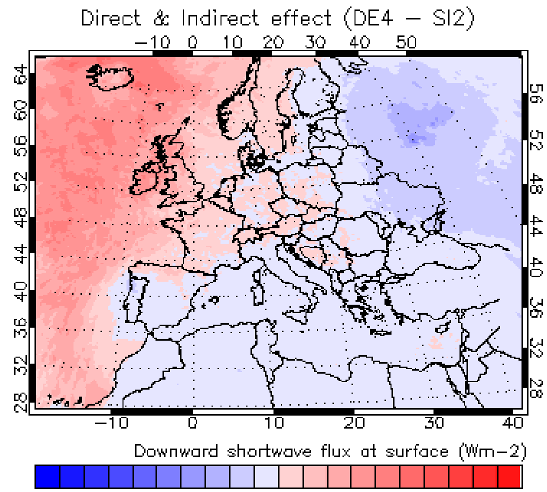


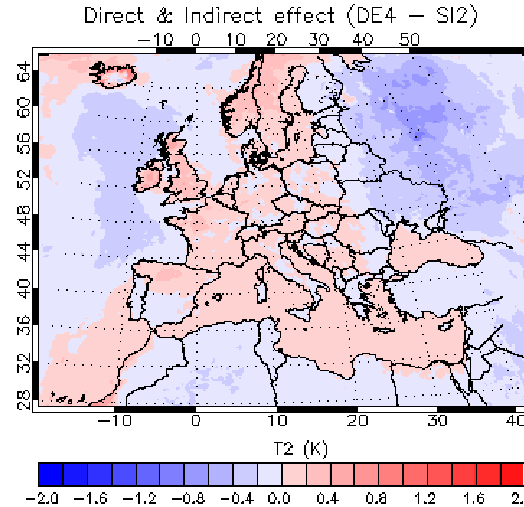
NO_x and PM10 measurement stations overlaid over corresponding emission maps. Symbols colored according to evaluation subdomain.

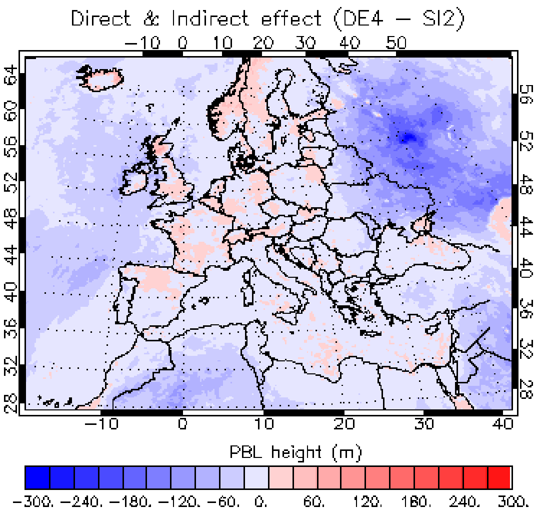
EuMetChem WG4 leader Dominik Brunner

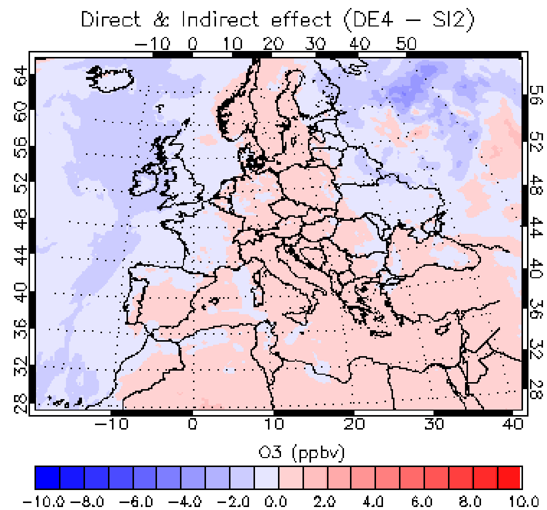
WRF-Chem Sensitivity Runs on 2010 Russian Fire Case Study: Chains of aerosol direct & indirect effects on meteorology







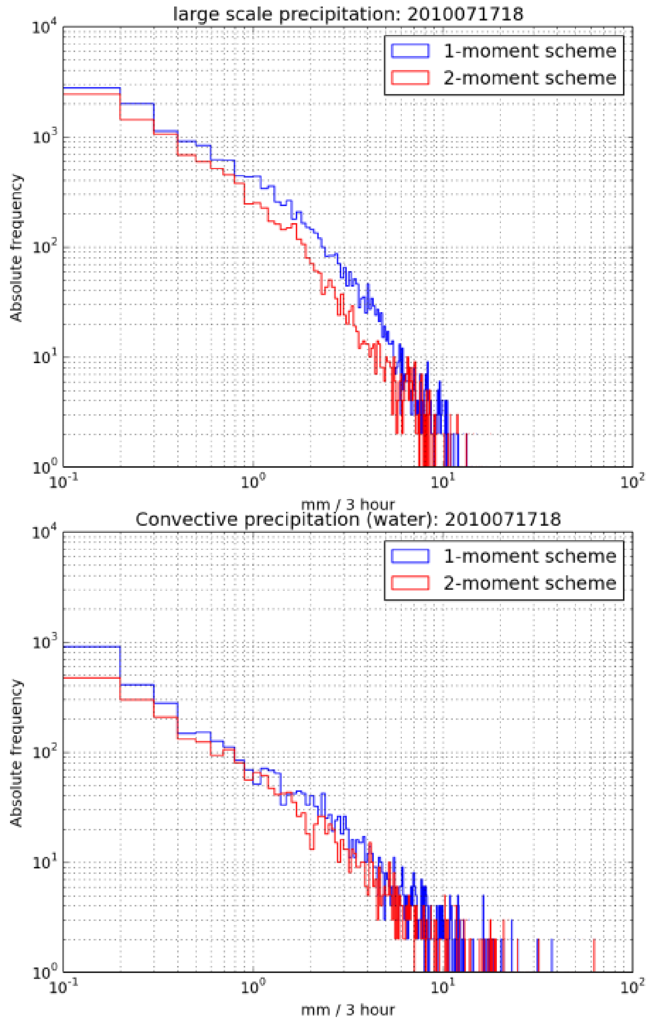




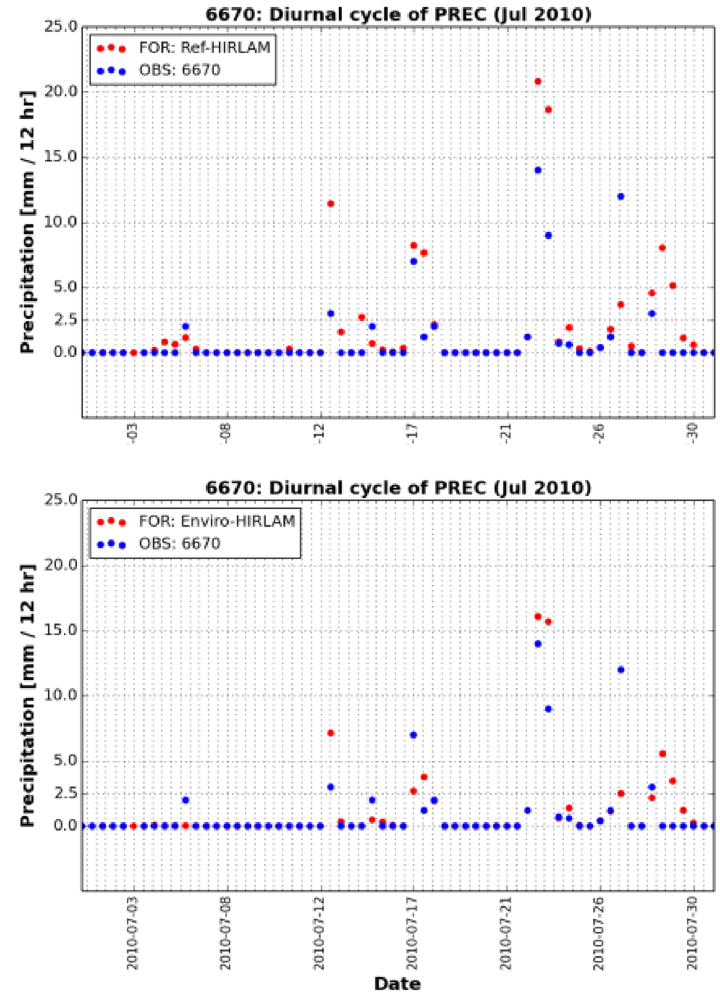
- Significant aerosol direct effects on meteorology (and loop back on chemistry).
- Reduced downward short wave radiation and surface temperature, and also reduced PBL height. It in turn reduced photolysis rate for O3
- The normalized mean biases are significantly reduced by 10-20% for PM10 when including aerosol direct effects.
- Indirect effects are less pronounced for this case and more uncertain.

Kong et al, AE, 2015

Enviro-HIRLAM: aerosol–cloud interactions



Frequency distribution in [mm/ 3 hour] of stratiform precipitation (top) and convective precipitation (down). Comparison of 1-moment (Reference HIRLAM) and 2-moment (Enviro-HIRLAM with aerosol–cloud interactions) cloud microphysics STRACO schemes.

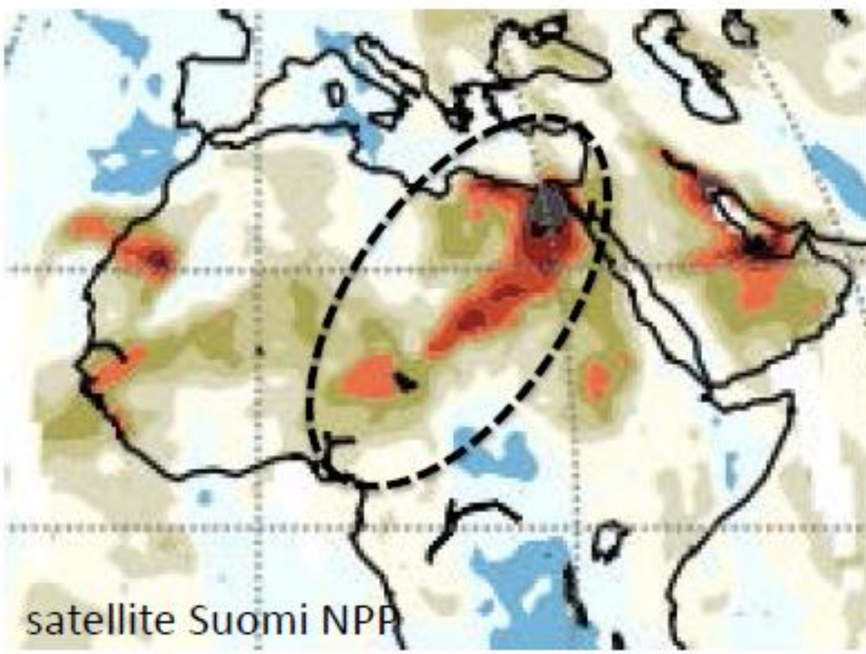


Precipitation amount (12 hrs accumulated) of reference HIRLAM (top) and Enviro-HIRLAM with aerosol–cloud interactions (down) vs. surface synoptic observations at WMO station 6670 at Zurich, Switzerland during July 2010.

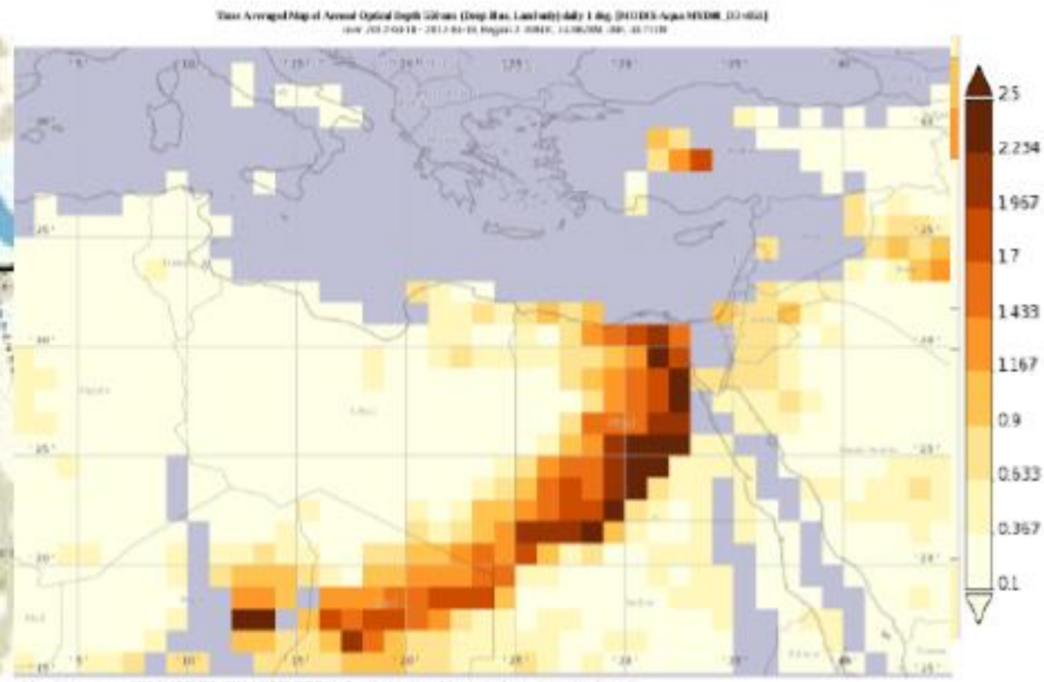
Nuterman et al, 2014

WGNE Exercise
Evaluating Aerosols Impacts on Numerical Weather Prediction

OMPS UV Aerosol Index
18 April 2012



MYD08_Aerosol_Optical_Depth_550_Land
18 April 2012



Case 1: Sahara Dust Episode
WMO WGNE Aerosol Task Leader Saulo Freitas, INPE

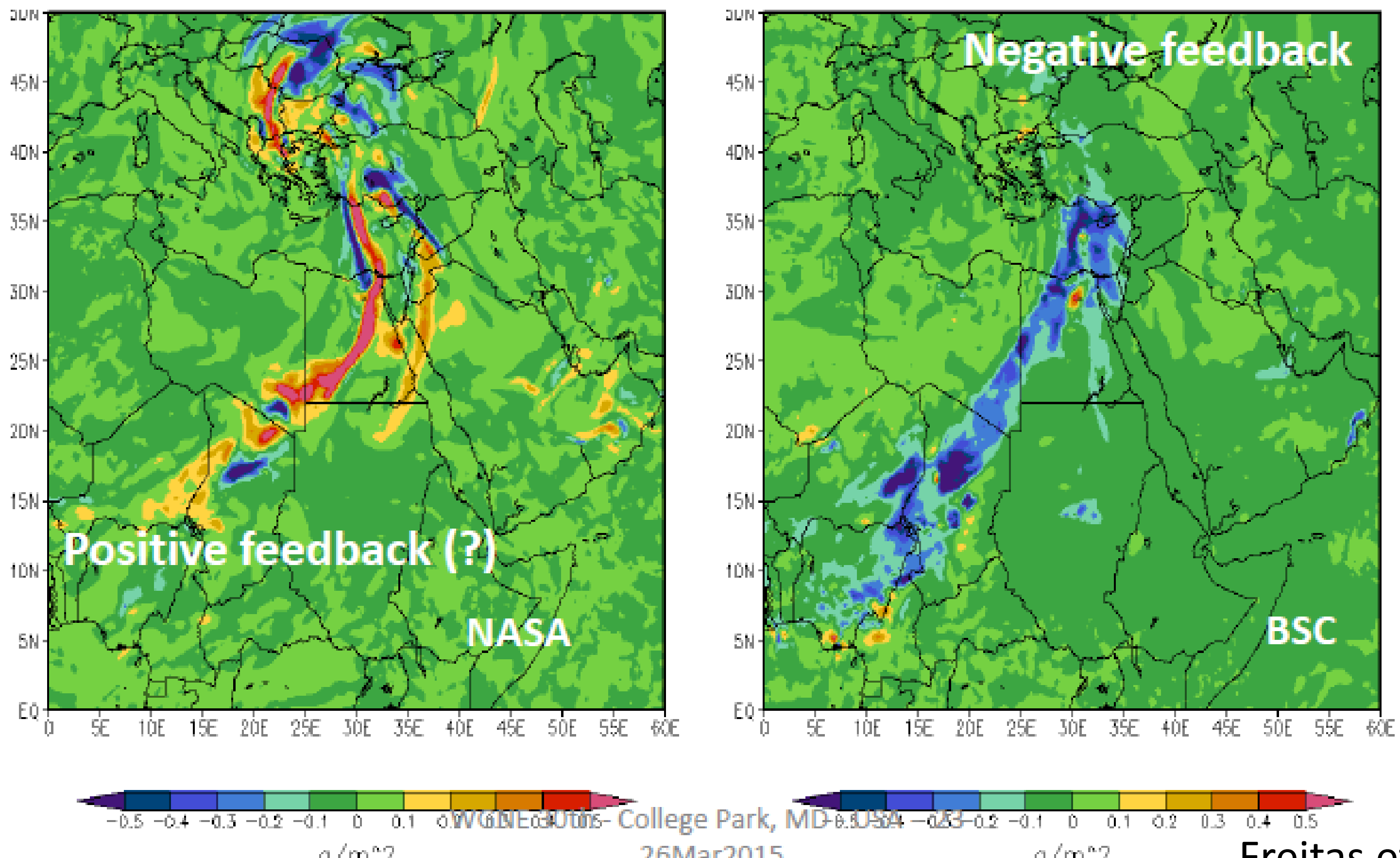
Freitas et al., 2015

How much interactive aerosol dust changes dust concentration itself?

Mass of dust column integrated (AER-NOAER)

forecast 09UTC18APR2012

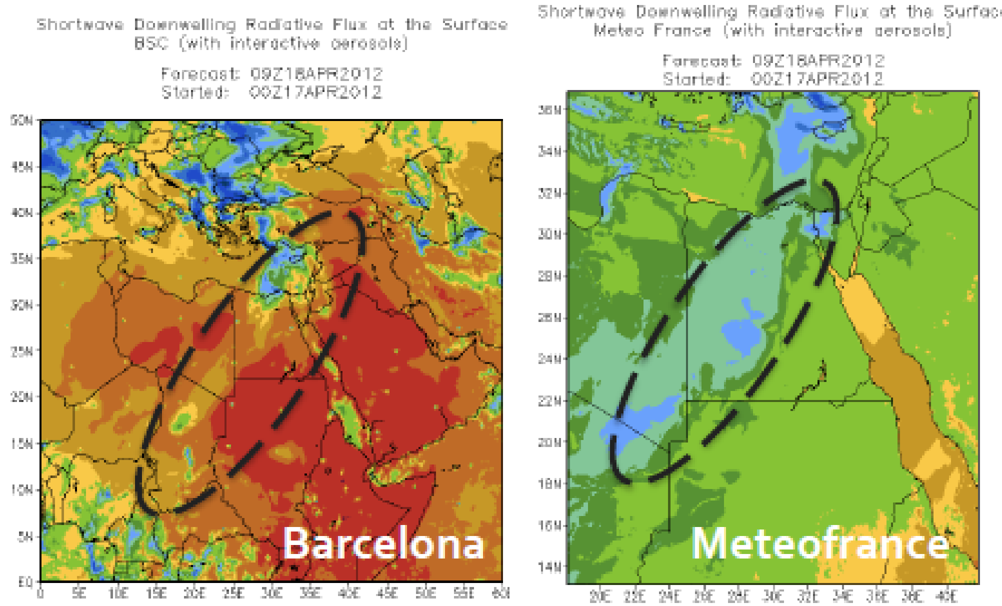
Init.:00UTC17APR2012



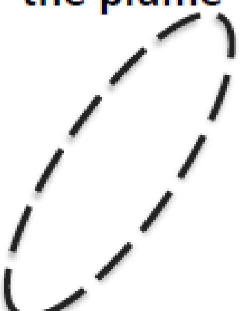
Freitas et al., 2015

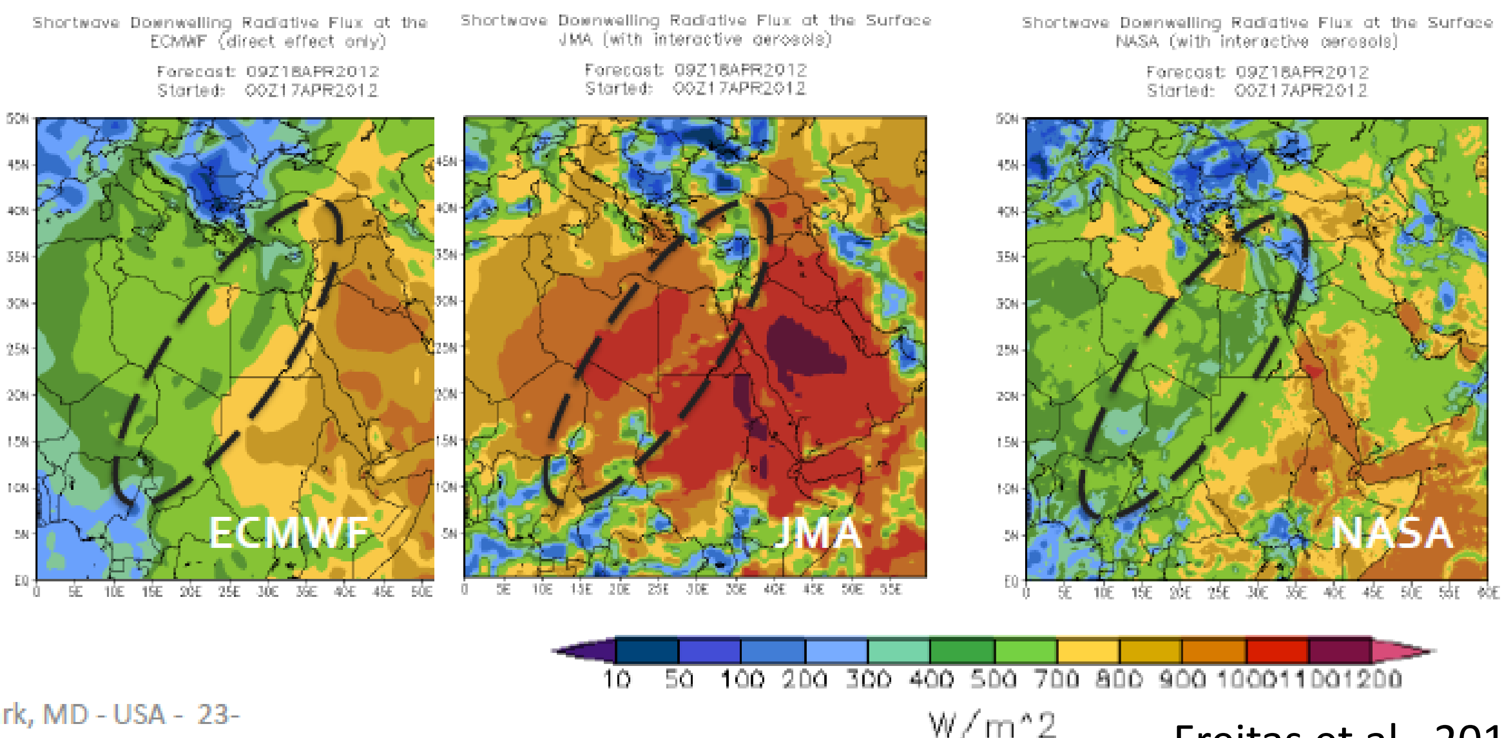
SW Rad @ Sfc Intercomparison

- 9 UTC (morning)
- Large discrepancies among centers



Location of the plume





Freitas et al., 2015

Case 2

Extreme Pollution in Beijing

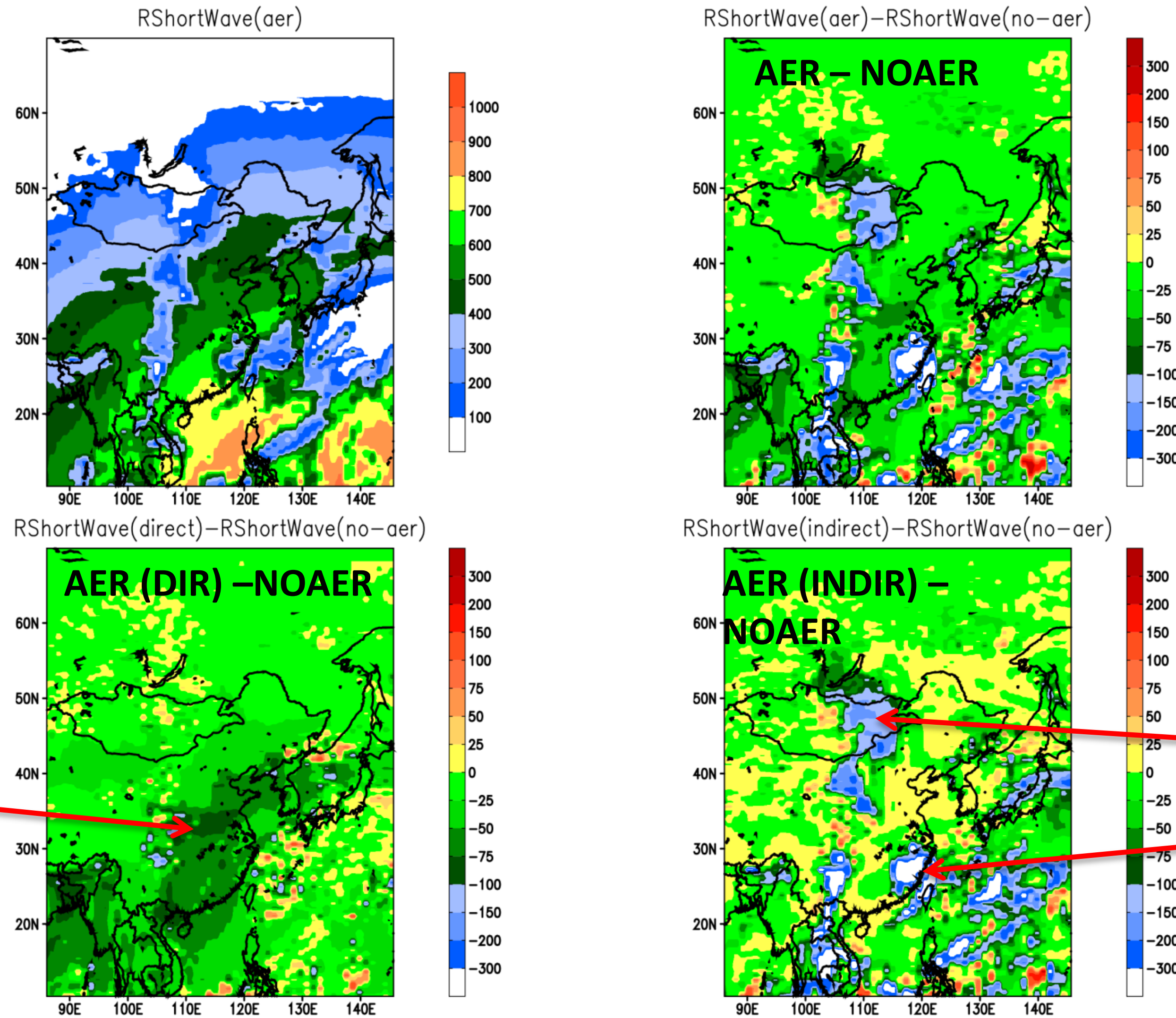
- January 2013
- Forecasts
  - January 7-21 2013
  - From 0 or 12 UTC
  - 10 day forecasts
- Center of domain
  - 116E, 40N
- Model configuration
  - Same as for NWP
- Direct & Indirect effects

So far, only JMA has submitted Indirect effect experiments.

Saulo Freitas, et al., 2015

JMA – Rad shortwave at sfc (W m^{-2})

Init 00UTC12JAN FCT: 03UTC14JAN



INDIR effect has more pronounced effect on sfc rsw extinction

DIR effect: -25 to -100 W m^{-2}

INDIR effect: -100 to -300 (or less) W m^{-2}

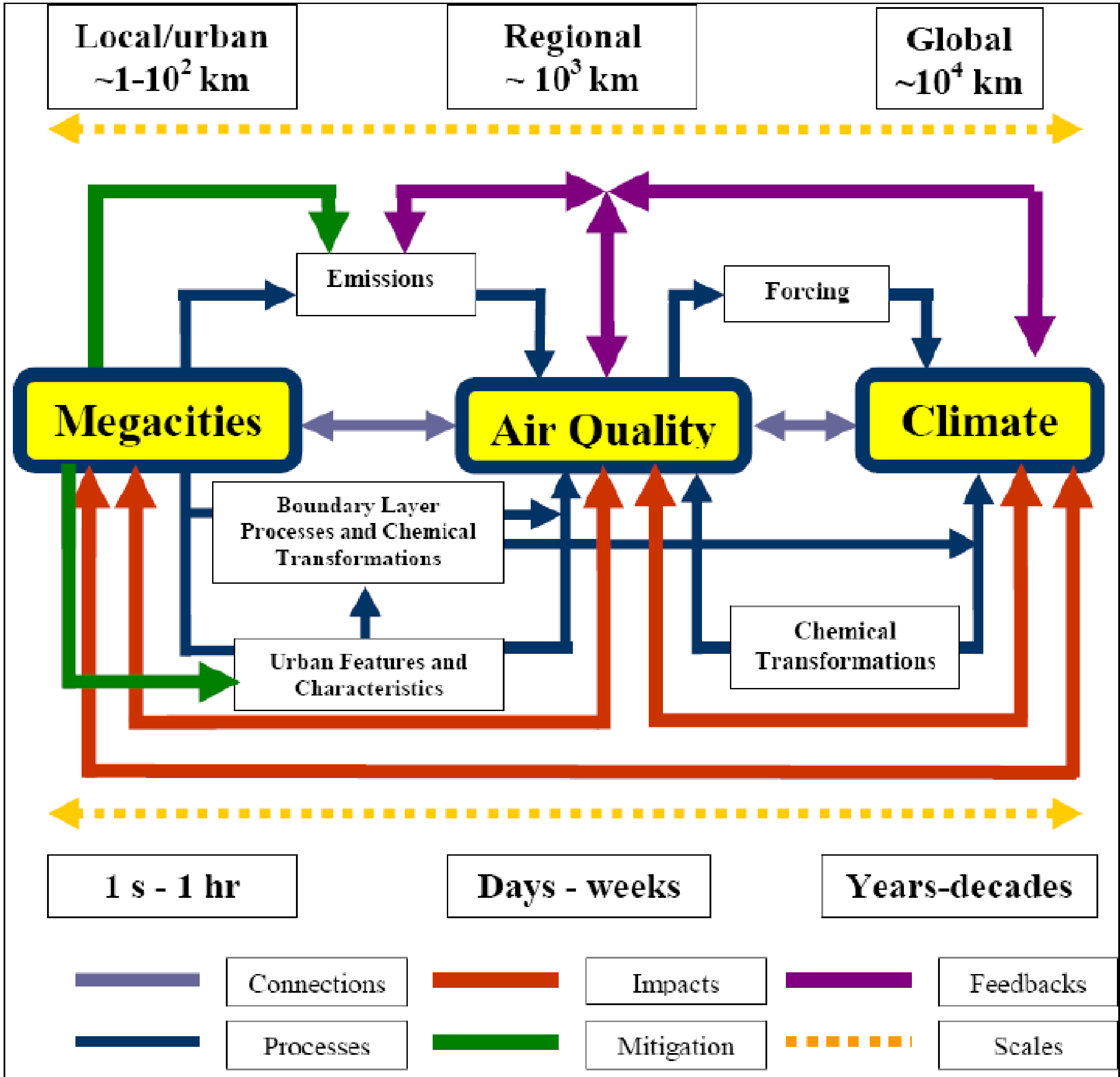
Freitas et al., 2015

Connections between Megacities, AQ, Weather and Climate

main feedbacks, ecosystem, health & weather impact pathways, mitigation

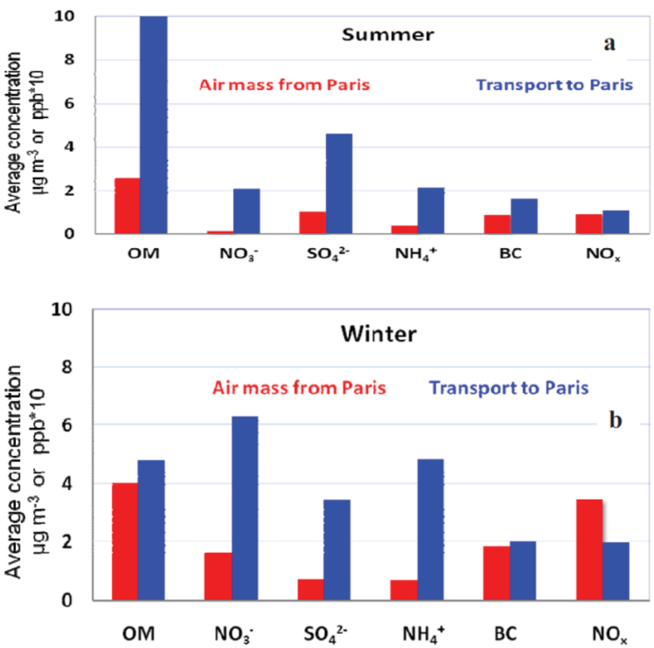
- Science - nonlinear interactions and feedbacks between emissions, chemistry, meteorology and climate
- Multiple spatial and temporal scales
- Complex mixture of pollutants from large sources
- Scales from urban to global
- Interacting effects of urban features and emissions
- FUMAPEX Integrated UAQIFS: in 6 EU cities

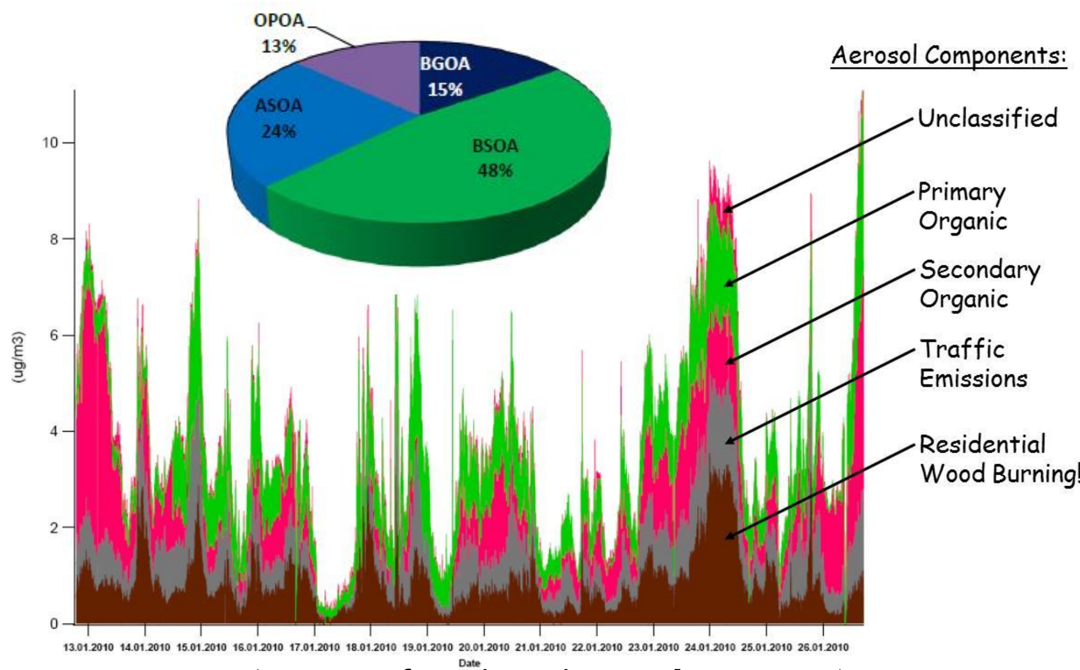
Nature, 455, 142-143 (2008)



MEGAPOLI Paris Measurement Campaigns

- Aim: Provide experimental data to better quantify sources of primary and secondary carbonaceous aerosol in a megacity and its plume. Duration: Summer – 1-31 Jul 2009, Winter – 15Jan-15Feb 2010
- 30 research institutions from France and other European countries, MEGAPOLI Teams & Collaborators





(Courtesy of Monica Crippa et al.; PSI Team)

- Surprisingly low fine PM levels
- 70% of fine PM mass is transported into megacity from continental Europe
- Fossil fuel combustion contributes only little to organic fine PM
- Large fraction of carbonaceous aerosol is of secondary biogenic origin
- Cooking and, during winter, residential woodburning are the major primary OA
- BC concentrations are on the lower end of values encountered in megacities worldwide.

(Beekmann et al., ACP, 2015)

CAS-16 priority: Urbanization: Research and services for megacities and large urban complexes

- Integrated Urban Weather, Water, Environment and Climate Services
- Focus on impact based forecast and risk based warnings
- Scientific issues: Requirements for observations; Near-real-time data assimilation; Coupling of air quality, meteorological, surface, hydrological processes; Seamless approach: scale interaction; High-resolution modelling: 'grey zone'.
- GURME: integral part of urban research and services

Online coupling for (i) NWP and MetM, (ii) AQ and CWF, (iii) Climate and Earth System modelling

- Relative importance of online integration and level of details necessary for representing different processes and feedbacks can greatly vary for these related communities.

- **NWP** might not depend on detailed chemical processes but considering the cloud and radiative effects of aerosols can be important for fog, visibility and precipitation forecasting, surface T, etc.

- For **climate modelling**, feedbacks from GHGs and aerosols become extremely important. However in some cases (e.g., for long-lived GHGs on global scale), fully online integration of full-scale chemistry is not critically needed. Still too expensive, so models need to be optimized and simplified.

- For **chemical weather forecasting and prediction of atmospheric composition**, the online integration definitely improves AQ and chemical atmospheric composition projections.

- **Main gaps**:
  - Understanding of several processes: aerosol-cloud interactions are poorly represented;
  - data assimilation in online models is still to be developed;
  - model evaluation for online models needs more (process) data and long-term measurements – and a test-bed.

What are the advantages of integrating meteorological and chemical/aerosol processes in coupled models for NWP?

- Advantages for episodes in relation to
  - health effects
  - aviation forecasts (icing, volcanic ash)
  - Radiation & surface temperature
  - Plume rise
- Cloud properties – probably.
- Precipitation - not yet clear.
- Benefits under ‘normal’ conditions not clear.
- Improving satellite retrieval of CO2 concentrations (and others?)

How important are the two-way feedbacks and chains of feedbacks for NWP?

- strong evidence for the importance of some of the model chains:
  - increased AOD -> lower surface T -> shallower PBL-> increasing primary pollutant concentrations
  - increased AOD -> lower surface T higher T above -> stronger stability-> convection inhibition
- Importance varies strongly with location (indirect effect more important in tropics?) and time (episodes) and with the model applied.
- For weather prediction the 3D real-time aerosol would most probably be important in specific cases of high aerosol concentrations.

CCMMs for air quality and atmospheric composition

Jose M. Baldasano, Véronique Bouchet, Rohit Mathur, Ana Miranda, Nicolas Moussiopoulos

Main Challenges and Gaps

- *Urban/stable boundary layer*: interactions between atmospheric chemistry and dynamics
- *Finer scale model applications* require frequent coupling between the dynamical and chemical
- Changes in *stratosphere-troposphere exchange and impacts on "background"* O_3.
- *Integrating emerging satellite observations* with CCMMs
- *Pollution scavenging and deposition* – inclusion of aerosol-cloud interaction
- *Need to evolve the way we compare grid based models with point observations*

Future Needs

- Continue intercomparisons both at global and regional scale for AQ, NWP and climate; should consider also intercomparison that are cutting across all 3 fields.
- Need some specifically defined experiment that looks at chemistry-cloud-microphysics at different scales.
- Need for (field experimental) data to evaluate online coupled models.
- Improving the numerical and computational efficiency of the models as the complexity of applications grows (e.g., scales).

CCMM Application Areas:

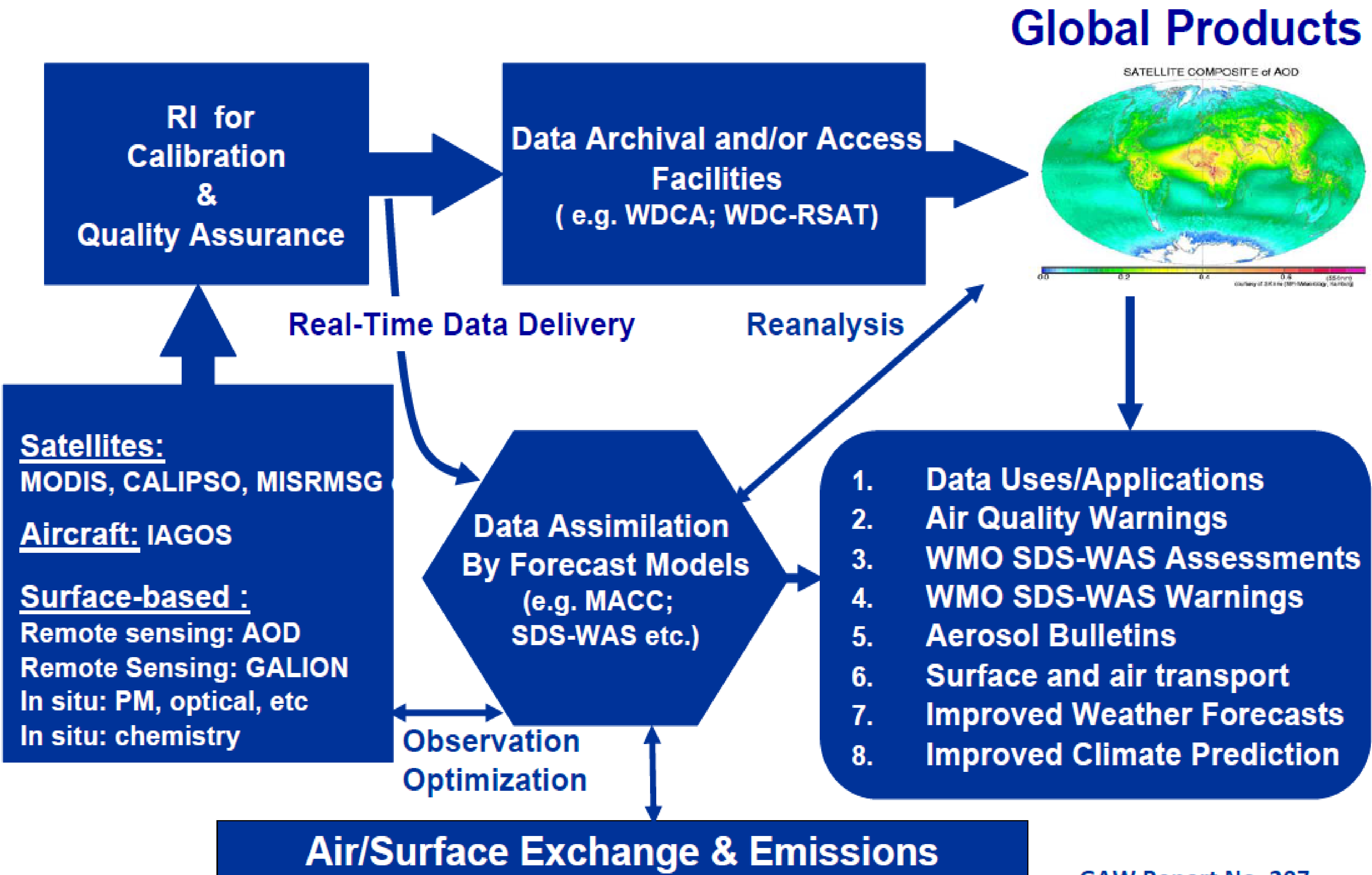
- Chemical weather / air quality forecasting and reanalyzes
- NWP for precipitation, visibility, thunderstorms, etc.
- Sand and Dust Storm Modelling and Warning Systems
- Wild fire atmospheric pollution and effects
- Volcano ash forecasting, warning and effects
- High Impact Weather and Disaster Risk
- Data assimilation for air quality and NWP
- Weather modification and geo-engineering
- Effects of Short-Lived Climate Forcers
- Earth System Modelling and Projections

New WMO GAW SAG on NRT Applications / Chemical Weather Prediction / Coupled Chemistry-Meteorology Modelling

AREP
GAW

WMO Global Atmosphere Watch (GAW)

Integrated Global Aerosol Observing System



GAW Report No. 207

WMO
OMM

AREP
GAW

Thank You !

World Meteorological Organization
A United Nations Specialized Agency
Working together in Weather, Climate and Water

COST ES1004 EuMetChem: http://eumetchem.info
WMO GAW and WWRP: www.wmo.int
GURME: http://mce2.org/wmogurme
MEGAPOLI: http://megapoli.info
EuMetChem AQMEII wiki-page: http://aqmeii-eu.wikidot.com/
AQMEII: http://aqmeii.jrc.ec.europa.eu/

Contact: abaklanov@wmo.int

Welcome to submit your papers to the ACP & GMD Special Issue
'Coupled chemistry–meteorology modelling: status and relevance for numerical weather prediction, air quality and climate communities':
http://www.atmos-chem-phys-discuss.net/special_issue241.html

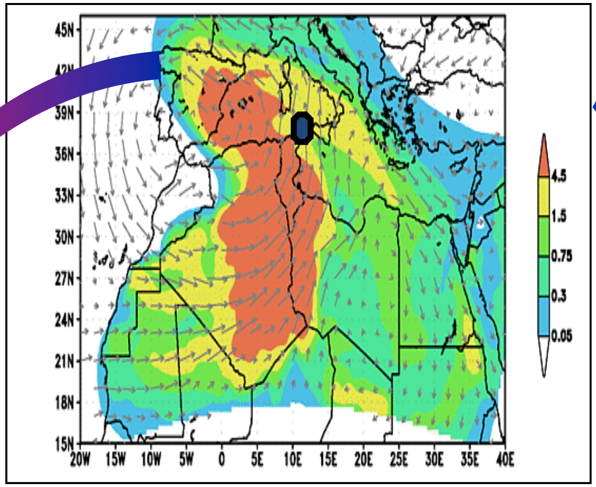
cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

WMO
OMM

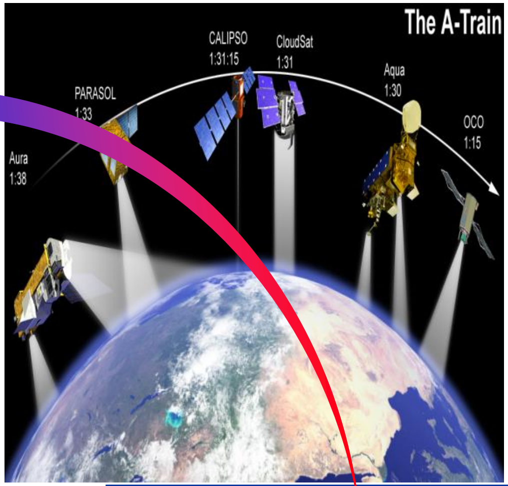
AQMEII
WCRP World Climate Research Programme
World Meteorological Organization
Weather • Climate • Water

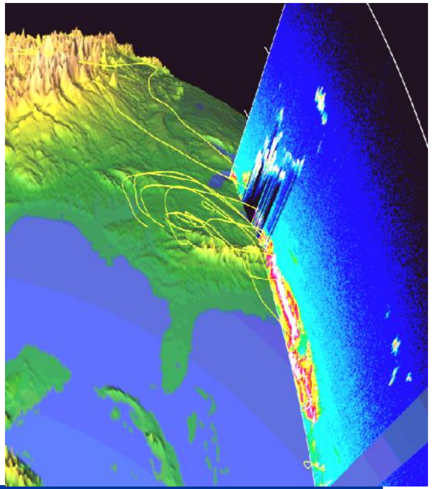
WMO Supported Aerosol and Weather Prediction Research

Forecast Models

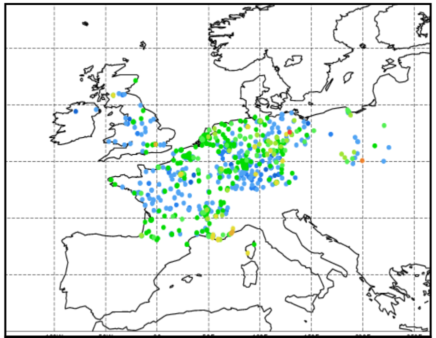


18 UTC, 7 May 2002 30-hr forecast

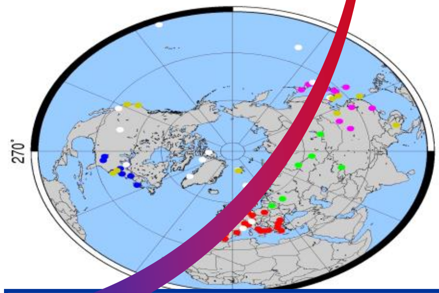




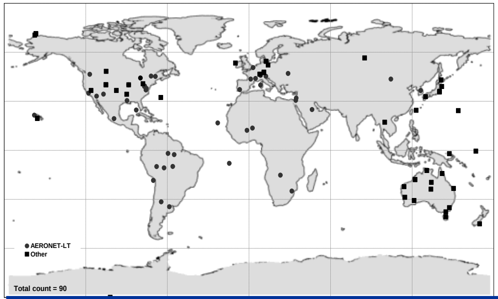
NASA A-Train MODIS CALIPSO
&
Geostationary Satellite IR Obs



European PM10



GALION
Surface-based LIDAR



GAW/AERONET/SKYNET
Surface-based AOD